Soil Sampling for Variable Rate Fertilizer and Lime Application

NCR-13 Committee

North Central Multistate Report 348

Minnesota Agricultural Experiment Station

University of Minnesota

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Publication design and development for the Minnesota Agricultural Experiment Station was by Larry A. Etkin, experiment station senior editor. Produced in the Communications and Educational Technology Services unit of the University of Minnesota Extension Service.

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Soil Sampling for Variable Rate Fertilizer and Lime Application

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Variable rate fertilizer application has become a major component of the fertilizer industry. The technology for its development has progressed in tandem with Differential Global Positioning Systems (DGPS), the two combining to provide for accurate "on-the-go" variation in fertilizer application.

The concept of site specific application of fertilizer is not new. Historically, fields were smaller than they are today and small areas within fields were frequently fertilized differently than the major portion in order to address special requirements for either nutrients used or rate of application. Today, computers and guidance systems have largely replaced techniques like counting rows or looking for atypical areas within a field. In addition, new technology such as the yield monitors and advances in aerial or satellite photography have increased the awareness of variability within fields.

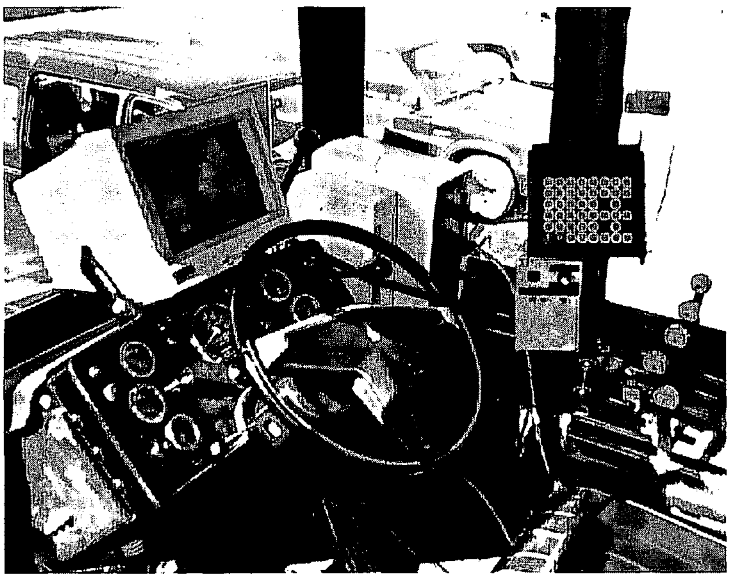
> ***"Computers and guidance systems have largely replaced techniques like counting rows or looking for atypical areas within a field."***

Regardless of the methodology used for site specific fertilizer application, the rate of fertilizer applied is still highly dependent on the results of the analysis of soil samples. These samples are intended to be representative of a field or a portion of a field. Even though the technology for fertilizer application has changed over the years, the purpose and/or objective for collecting the samples has not. The information generated from the analysis of soil samples should either:

1) provide the information necessary for accurate fertilizer application, or
2) be used as a basis for monitoring changes in soil test values that may take place over time.

These changes are primarily the consequence of manure, fertilizer use, and cropping history.

This publication is intended to provide a current summary of thoughts on the subject offered by various researchers and/or Extension faculty. Statements made should not be considered as firm recommendations for future use for all fields. Several active research programs are currently focusing on soil sampling strategies that could be appropriate for variable rate fertilizer application. So, as research projects are completed, a strategy suggested today may change in the near future.



Technology in the form of Differential Global Positioning Systems guides appropriately equipped tractors with the precision that makes variable rate applications of fertilizer possible.

Various sampling strategies that might be used as a basis for variable rate fertilizer application have evolved. Several factors can affect the sampling strategy that will be used. For example, cause of the variability (natural vs. man-made) is an important consideration in strategy selection. In addition, the strategy used for sampling immobile nutrients probably should not be the same as the one used for sampling for the nutrients considered to be mobile. Tillage system also has a major effect on sampling strategy because of differences in fertilizer placement. When results of current research efforts focused on sampling are evaluated, it's obvious that there is no single optimum strategy for collection of soil samples for measurement of all nutrients in all production systems.

Grid Versus Zone Sampling

In general, there are two sampling strategies (grid, zone) that can be used to direct site-specific fertilizer and lime application. Grid sampling uses a systematic approach that divides the field into squares or rectangles of equal size (usually referred to as "grid cells"). Soil samples are collected from within each of these "cells." The location of each "grid cell" is usually geo-referenced using global positioning system technology.

When using the grid strategy, there is an assumption that the variability of soil pH and immobile nutrients within fields cannot be easily identified. The results of the analysis of soil samples collected with the grid sampling strategy may be used directly for fertilizer or lime recommendations (in effect, treating each grid as a small field), or they may be entered into a mapping program that uses geo-statistics to draw fertilizer application boundaries. In both situations (grid, zone), the results of the soil sampling and analyses are used to define the boundaries of the areas receiving different rates of fertilizer or lime.

Zone sampling, on the other hand, uses a more subjective and intuitive approach to divide any field into smaller units. Soil samples collected at random from within each zone are bulked together and analyzed to provide an average sample value for each unit. This approach assumes that variability of soils within a field can be easily identified. For example, soils with different percentages of organic matter can be distinguished by color and, therefore, can be sampled separately. Information from a yield monitor may be helpful in identifying zones that should be sampled separately. As with the grid system, sampling points can be geo-referenced.

There have been and continue to be arguments for choosing one sampling strategy over the other. In reality, both may be appropriate in specific situations. The following are criteria that would favor the use of the "grid" sampling strategy.

- a measure of non-mobile nutrients is the primary concern; with no movement, distribution will be affected less by topography and other fixed properties.
- the soil test levels in the field range from very high to very low with substantial acres in both the very high and very low categories; management practices used in the past will override natural variability
- there is a history of manure use
- small fields have been merged into large fields; differences in past management may have larger influence on soil test levels than natural variability
- the field history is not known

The criteria that would favor the use of zone sampling are:

- cost of sampling and analysis is a major concern; zones may be larger than grid cells thereby lowering sampling costs
- a measure of mobile nutrients is the primary concern
- relatively low rates of fertilizer have been applied in recent years
- there is no history of manure application
- the history of the field is known and can be used to divide the field into smaller units; a more accurate judgement can be made when all available information is used.

Instead of thinking about either grid or zone sampling, a more logical approach might be a combination of the two strategies. This approach would consist of imposing a grid on zones in a field identified by:

1) observation,
2) a modern soil survey, or
3) information obtained from a yield monitor.

This combined strategy would increase the costs of sampling and analysis relative to the zone approach, but it would have the advantage of providing a measure of the variability within zones, and possibly uncovering variation due to past management that had not been otherwise accounted for.

Regardless of the sampling strategy preferred by the farmer or crop consultant collecting the samples, intensive sampling is an improvement over the more traditional approach of collecting samples at random from a field with subsequent fertilizer recommendations based on this field average.

Sampling For Immobile Nutrients

The grid cell system is frequently used when measurement of immobile nutrients and soil pH is the primary objective. The practice of collecting soil samples in a grid pattern to support variable rate fertilizer and lime application has raised several questions. Those most frequently asked are:

- When does it pay?
- If samples are collected from the same location each time, are soil test values for immobile nutrients constant during the growing season?
- How should samples be collected from a specific grid cell or zone?
- What is the optimum size of the grid cell?
- How frequently should samples be collected when the analytical results are used for variable rate fertilizer applications?

Economics of Grid Sampling Strategies

The economic benefits of grid sampling are neither clear nor clearly documented. Since any intensive sampling program represents an increased cost over conventional sampling, there must be an offsetting economic advantage from either increased crop yields, or reduced fertilizer costs.

Increases in crop yield would be expected if intensive sampling identifies parts of a field that could respond to higher rates of fertilizer than normal and the added fertilizer increases yield in those areas. Savings from reduced fertilizer application could be realized if nonresponsive areas of a field are identified and fertilizer application for those areas is reduced. The challenge is to identify opportunities for increased net income with sufficient precision, but without excessive cost.

Table 1. Mean soil test values for P (0 to 6 inches) in parts per million, measured by the Olsen soil test procedure and time of sampling.

	Time of Sampling		
Site I.D.	*Spring Year 1*	*Fall Year 1*	*Fall Year 2*
F	*13.7*	*10.8*	*8.6*
M	*11.4*	*11.7*	*7.8*
RA	*14.3*	*10.7*	*11.8*
S	*20.6*	*21.2*	*23.9*

Table 2. Mean soil test values for K (0 to 6 inches) in parts per million, measured by the ammonium acetate procedure and time of sampling.

	Time of Sampling		
Site I.D.	*Spring Year 1*	*Fall Year 1*	*Fall Year 2*
F	*152*	*159*	*145*
M	*136*	*155*	*191*
RA	*152*	*207*	*269*
S	*255*	*262*	*269*

Variation in Soil Test Values Over Time

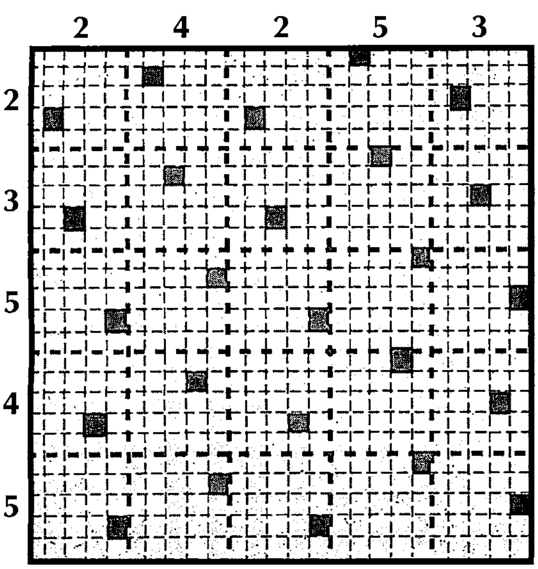
In recent years, several research projects have been initiated to provide answers to one or more of these questions. Research conducted in four fields in Minnesota showed that the spatial patterns of soil test values for phosphorus remained relatively constant over the growing season if the soil cores were collected from the same location at each time of sampling (Table 1). Even though soil test values declined over time, there was still enough variability to be a cause for concern.

There is also general agreement that soil test values for potassium fluctuate with soil moisture content at the time of sampling. For potassium, values for samples collected throughout a growing season may show wide fluctuations. The fluctuation in soil test K in four Minnesota fields is shown in Table 2. Therefore, when a field is sampled repeatedly over time, the samples should be collected at the same time each year. This practice should eliminate some variability in soil test values. For example, if samples are usually collected from a field in the fall, a continuation of the fall sampling strategy is recommended.

Sampling Strategy for Grid Cells

The procedure that should be used in a grid cell system has also been the focus of field research. It's important to remember that regardless of the procedure used, the sample collected should provide the best representation of the area sampled. A stratified, systematic, unaligned strategy is one that has been proposed. With this procedure, location of a point to be sampled in each grid cell is predetermined and each point from which a sample is taken is geo-referenced. If this procedure is followed, soil is collected from one location or point in any grid cell. Frequently, the sample that represents the point consists of six or more cores taken from an area with a radius of two or three feet. One example of this sampling system is illustrated in Figure 1.

Figure 1. An example of a stratified systematic unaligned grid of points to be sampled to support variable rate application of immobile nutrients.



Use of this suggested sampling procedure raises serious concerns. If the predetermined pattern is strictly followed, it is possible, if not probable, that soil collected from a single point in a cell may not be representative of the true fertility status of the cell. It is possible, especially for farms with an animal agriculture base, that variability in the soil test values for any immobile nutrient within an individual cell may be as great as or greater than the variability in soil test values for that nutrient across an entire field.

The small scale variability of phosphorus both along rows and across rows has been documented by Mallarino (Figure 2). The magnitude of this small scale variability is a strong argument against the use of any point sampling system. Analysis of any non-representative sample could easily lead to incorrect application of fertilizer over an extensive area.

Use of a non-aligned system should allow for flexibility. Those who spend a considerable amount of time collecting soil samples realize that variability is a common characteristic of most fields. Even when the non-aligned system is used, collection of samples from points that are not typical of the remainder of the grid cell should be avoided. This same caution has always applied to the collection of soil samples, even those collected at random on a field scale basis.

Figure 2. Variability in soil test values for phosphorus along and across corn rows in eight fields in Iowa.

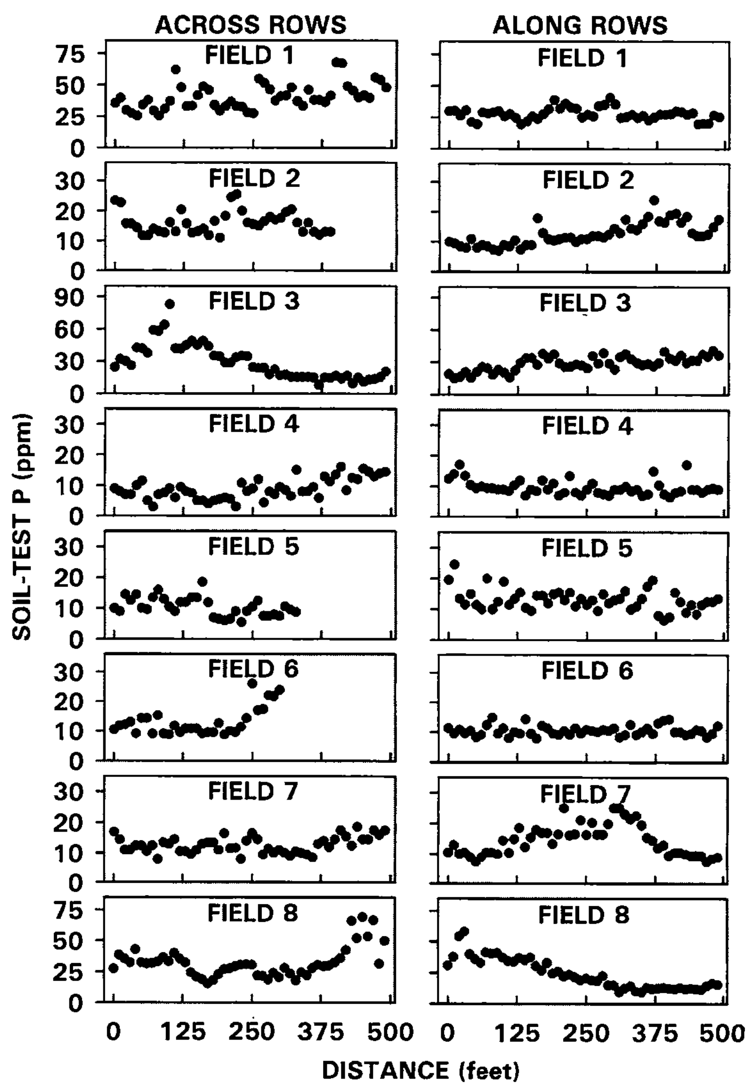
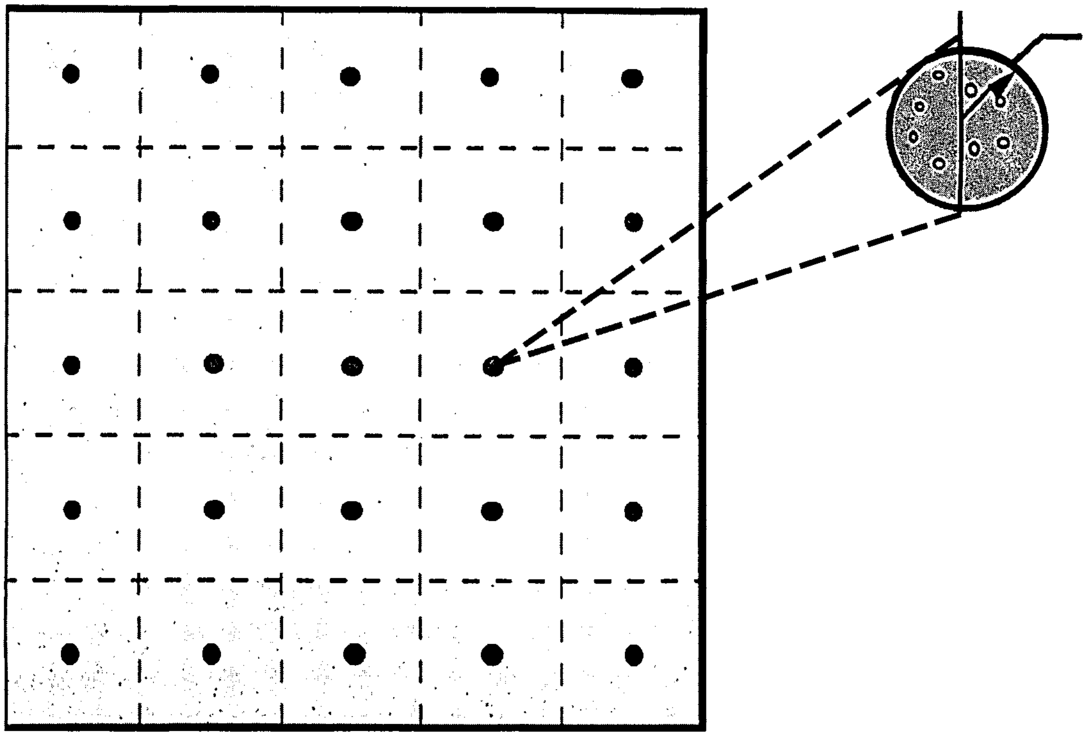


Figure 3. An example of a systematic sampling pattern for square grid cells. A grid of equally spaced lines is established, eight soil cores are randomly collected within a 10-foot radius of the grid center, and the cores are composited as one soil sample.



A systematic grid cell sampling procedure has also been proposed. With this procedure, the field to be sampled is first divided into grid cells that are uniform in size. The soil sample is collected from a point in a grid cell (usually the center). The location of the point of sample collection is the same for all grid cells. This sampling procedure is illustrated in Figure 3.

The concerns expressed for the stratified systematic unaligned procedure are appropriate for the systematic grid cell procedure. Even though the point of collection is geo-referenced, there is genuine concern that the nutrient status at one point in the grid cell is not the same as the nutrient status of the remainder of the soil in that cell.

Grid cells can also be sampled with a random technique where there is no definite procedure. Several cores are collected from within a grid cell and composited to make one sample. The number of cores needed is not defined and this decision is usually made by the individual collecting the samples. Remembering the amount of small scale variability present in fields (Figure 2), a larger number of cores provides a better representation of the fertility status of the grid cell. The procedures used in the random sampling of grid cells are probably as varied as the number of individuals collecting the samples.

Sampling procedures used can be described as point, multi-point, and random. The effectiveness of these three strategies has been evaluated by research with phosphate fertilization over a variable landscape. For this research effort, 10-acre portions of fields were sampled intensively, several rates of phosphate fertilizer were applied to assigned strips, and yields were recorded for small segments in the experimental area. Since the intensive sampling procedure (60 foot square cells) was used, various sampling strategies were evaluated by comparing soil test phosphorus (P) values to yield response.

Phosphate fertilizer recommendations that evolved from the analysis of the soil samples for P were used to evaluate and compare the three sampling strategies. This information from three sites is summarized in Table 3. For the random sampling procedure, soil test values were used from nine locations in a grid cell that measured 180 feet square. Soil sample values from five locations in this cell were used for the multi-point procedure. The soil test value from the center of each cell was used for the mid-point procedure.

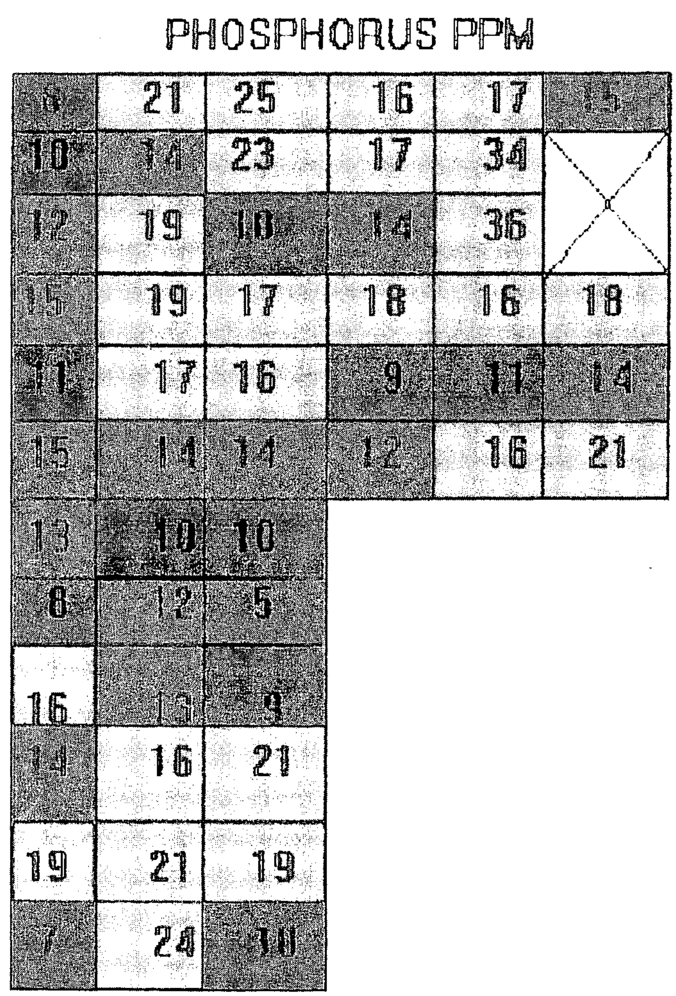
Because of the larger number of sites used in sample collection, the phosphate recommendations evolving from the random sampling procedure were used as the standard for comparison. Overall soil test values for P at the Sibley site were high generating phosphate recommendations that were low. By contrast, phosphate recommendations were higher at the Renville A and Renville M sites. Use of the mid-point sampling procedure produced higher recommendations at these two sites.

Variability of soil test values for P and K has been documented at various scales. Research and experiences of those who collect soil samples leads to the conclusion that variation is substantial. Therefore, regardless of the procedure chosen for sampling grid cells, several cores taken from the cell are preferred. However, there is no single recommended procedure for sampling grid cells at this time.

When grid cell sampling is used, there are various preferences for the size of the grid cell to be sampled. When grid sampling was first introduced, most who collected the soil samples used a grid cell size of 4.5 acres. More recently, the preferred size has been reduced to about 2.5 acres. This reduction in size in-

Table 3. Phosphate fertilizer recommendations (in pounds of P_2O_5 per acre) for corn production as affected by the procedure used for sampling grid cells.

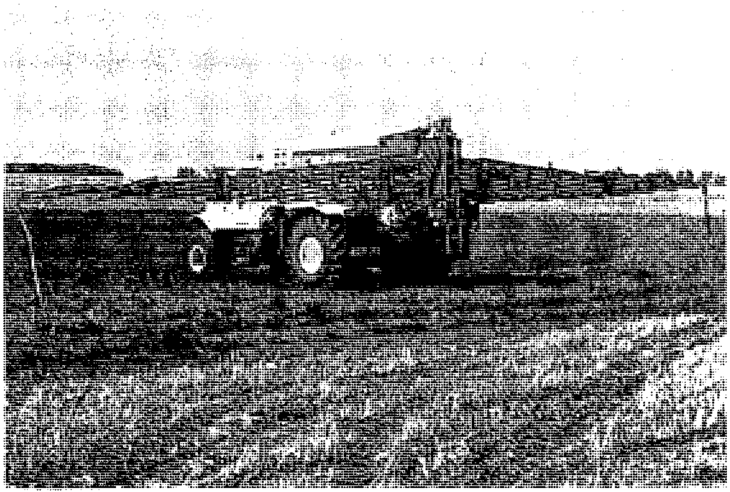
	Location		
Sampling Procedure	*Renville A*	*Renville M*	*Sibley*
point	*40*	*29*	*13*
multi-point	*27*	*25*	*10*
random	*25*	*11*	*9*



The output of a grid sampling for phosophorus might look approximately like this. Numbers within the grid cells are soil test values for phosphorus as measured by the Bray procedure.

creases the accuracy of the subsequent fertilizer recommendation. The cost of sampling, however, increases.

Cost of sampling can be minimized by sampling fields less frequently. For example, past recommendations were to sample a field in a corn/soybean rotation once every two years. With more intensive, geo-referenced sampling, a sampling frequency of once in four years is proposed. Soil test values for the immobile nutrients do not change rapidly over time. Therefore, sampling frequency can be extended to once in four years to reduce the cost of more intensive sampling.



Equipment for variable rate application of fertilizer is important for modern agriculture. The variable rate application concept is based on accurate collection and analysis of soil samples

For fields which have highly variable soil test values for P and/or K, it would be logical to sample certain portions on alternate years. For example, if a cell having high soil test values is adjacent to a cell having very low levels, it would be appropriate to sample each cell every two years or collect samples on the adjoining edges of the respective grid cells.

Suggestions for procedures to be used in sampling grid cells also apply to sampling when a zone sampling strategy is used for immobile nutrients. Locations from which a soil cores are taken should be geo-referenced. The sample representing any zone should consist of soil cores taken from several locations within that zone. A sampling frequency of once in four years would also be appropriate for this sampling procedure.

Sampling Strategy for Zones

In general, mobile nutrients in soils are dynamic and concentration of any form of that nutrient changes constantly. The rate of change among the various forms is highly dependent on environmental factors. There is, however, no reliable way to predict the rate at which these changes take place. Nevertheless, there can be strong relationships between basic soil properties and the rate at which some reactions affecting mobile nutrient concentration take place. Therefore, zone sampling procedures are probably more appropriate because relative levels of a mobile nutrient are frequently related to fixed soil properties.

When considering zone sampling, it's important to point out that it's not easy to determine where to draw the line between one topographic position and another. Past management practices such as fertilization, cropping history, manure use can be used to define zones. Topographic maps and aerial photographs can also be used. In North Dakota, there was a good relationship between soil nitrate measurements and topography if measurements were made on a 110 foot grid.

The County Soil Survey can be a tool to assist with zone sampling along with other soil property information. In North Dakota research, the Order 1 Survey (1 to 5,000 scale) shows a better relationship between soils that are mapped and measured soil properties. It should not be the only tool. The County Soil Surveys should be used as a general guide that can be refined by information from other sources (aerial photos, topography maps, yield maps, etc.).

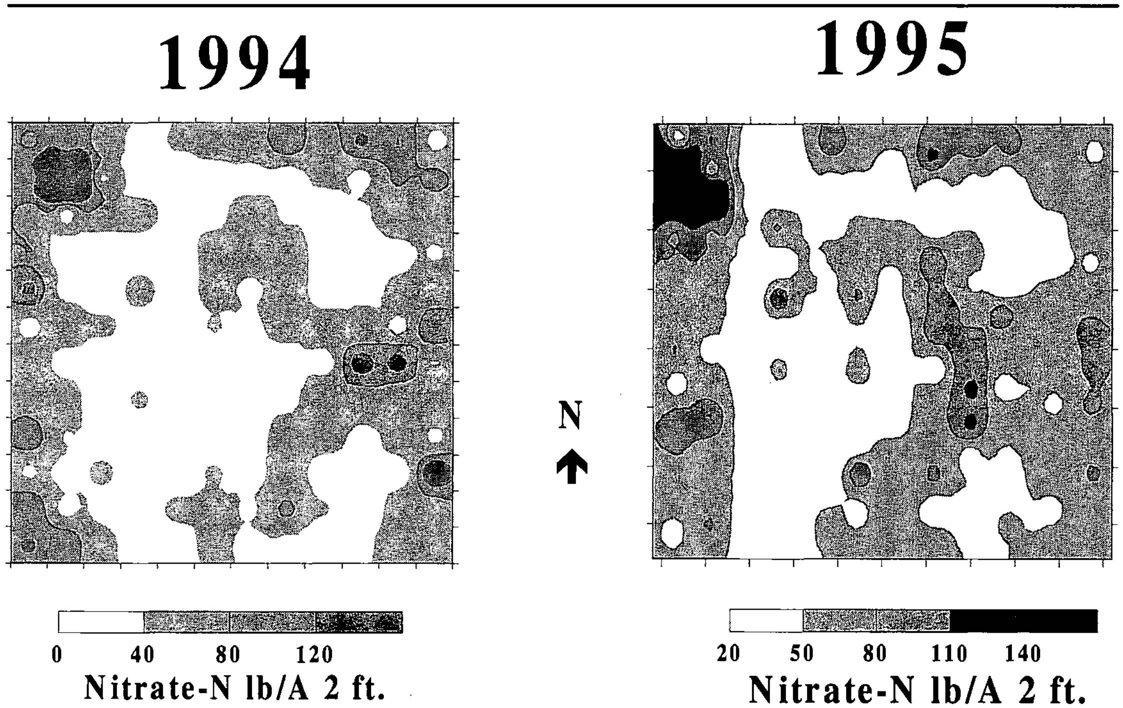
The zone sampling approach should also use common sense. In many situations, changes in topography are obvious. These can usually be matched to the soil types identified in a Soil Survey. If there are obvious visual differences in soils across a landscape, these soils should be sampled separately.

Soil pH is frequently related to topography and landscapes. Soil texture and organic matter will affect the buffering capacity and rate of acidification of soil. This is particularly true in humid climates. Differential erosion will also create patterns of pH variability in various places on the landscape.

Studies in North Dakota have led to the conclusion that permanent or fixed soil properties such as topography, organic matter content, and electrical conductivity (EC) maps, are related to the spatial variability of nitrate, sulfate, and chloride in soils. Topography affects the movement of mobile nutrients. Organic matter content is usually higher in depressions than on the higher positions of the landscape. In drier climates, the mobile nutrients tend to accumulate in the depressional areas. With higher rainfall and the need for tile drainage, the mobile nutrients may be lost through the tile lines. As a result, lower concentrations may be found in the depressional areas. A relationship between mobile nutrients and soil topography in one area of North Dakota, illustrated with readings from two consecutive years, is shown in Figure 4.

Locations from which soil cores are taken should be geo-referenced when zone sampling is used. This helps in interpretation of the laboratory analysis of samples collected in the future. Regardless of the pattern used for the collection of samples, it's still important to collect samples from the same position on the landscape each time that the field is sampled. Depth from which the sample is taken should also remain the same over time.

Figure 4. Year-to-year variability is illustrated with two successive years of soil nitrate-nitrogen levels shown for a depth of 0-2 feet in a field in Valley City, North Dakota. First year measurements followed a spring wheat crop. Second year followed a uniform application of 100 lbs/acre N and a sunflower crop.



Considerations For Conservation Tillage

Use of conservation tillage production systems (ridge-till, no-till, strip-till) creates special situations for soil sampling. Use of banded application of immobile nutrients is a major management practice and this must be considered when soil samples are collected from fields where conservation tillage production systems are used.

A Proposal for a Guiding Equation

If the position of the band is known, some researchers have proposed that the following equation can be used to determine the number of cores taken outside of the band for each core taken near the anticipated location of the band. The equation is:

$$CN = 8\left[\frac{BS}{12}\right]$$

Where:

CN =number of cores taken outside of the band for each core taken in the band

BS =spacing between bands in inches

For example, eight cores would be needed from outside the band for eachcore taken in the band if the spacing between bands was 12 inches, or 20 cores would be needed from a 30-inch spacing. It is emphasized that this is a proposed equation. There is no universal agreement that this equation provides the best guide for sample collection.

Both grid cell and zone sampling strategies can be used when conservation tillage is practiced and recommendations made for each sampling strategy apply. However, special consideration should be given to the location of the cores with respect to the row. Since the location of the band of immobile nutrients is frequently known, it is possible to collect cores from the band as well as between existing bands.

Several cores (20 to 30) are needed for an accurate sample if the location of the band in the conservation tillage system is not known. Thorough mixing of these cores is needed before a subsample is selected and sent to the laboratory.

In ridge-till and no-till planting systems, the band of immobile nutrients is usually applied in the fall with the next crop planted directly over this band. For these planting situations, soil cores taken to a depth of six inches at a distance of approximately six inches from the row will provide the best information needed for phosphate and potash recommendations.

The variability in soil test values for an immobile nutrient in a field, both parallel to the row and across rows, can be substantial and is not predictable. Therefore, several cores are needed for an individual sample.

Summary

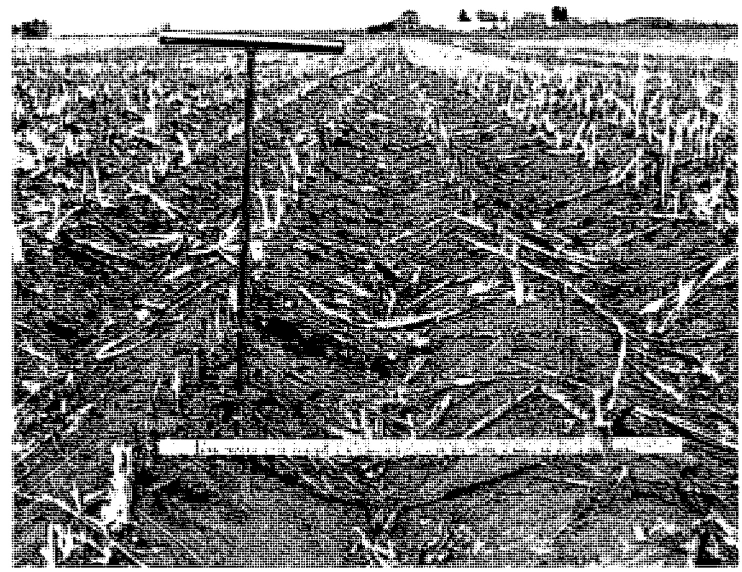
Precision in the application of fertilizer is highly dependent on the information derived from the soil samples collected for that purpose. Therefore, from a nutrient management perspective, the sample collected should provide the best representation of the area sampled.

To guide more precise fertilizer applications, existing fields are divided into smaller fields and sampled accordingly. Regardless of the method used for dividing fields into small segments, accuracy is improved if more information is used to guide the fertilizer application.

To generate the information needed to support variable rate fertilizer application, fields are divided into either grid cells or zones. In general, grid cells are used where recommendations for use of immobile nutrients are the major concern. Zone sampling appears to be most appropriate where application of mobile nutrients is the major concern.

Regardless of the strategy used–grid cell or zone–it is necessary to collect soil from several locations within any defined area. Point sampling does not provide the best predictive information.

Considerable research has been devoted to developing sampling strategies for variable rate fertilizer application. The recommendations that have evolved are consistent with recommendations made for sample collection in the past. Considering economics and practicality, accuracy of fertilizer recommendations increases as the number of cores taken per sample increases.



Variable rate applications of fertilizer or any soil amendment would have been impractical to the point of being impossible without the development of technologies for precision farming. Manual soil cores could not be tsaken with sufficient frequency across large acreages, nor could they have been analyzed with sufficient speed.

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Minnesota Agricultural ExperimentStation Bulletin 608-2001
Distribution Center Item SB-7647-S